Proceedings – 23rd Annual Conference – IEEE/EMBS Oct.25-28, 2001, Istanbul, TURKEY

THEORETICAL AND EXPERIMENTAL STUDY OF EM FIELDS AND SHIELDING EFFECTIVENESS DUE TO HIGH VOLTAGE TRANSMISSION LINES

S.S. Şeker, F. Can
Boğaziçi University, Dept. of Electrical-
Electronics Engg. 80815 Bebek, İstanbul, Turkey
seker@boun.edu.tr

O. Çerezci
Sakarya University, Dept. of Electrical-
Electronics Engg, Sakarya, Turkey

Abstract: In this study, the EM fields produced by high power 3-phase transmission lines are investigated. The dependence of the magnetic field with respect to vertical and horizontal distances from the transmission lines are illustrated and the minimum distance from the lines for human safety is specified according to ICNIRP standards.

In addition, a quasi-static examination to the magnetic shielding of several enclosures are performed. In the analysis, the integral form of Maxwell's equations with boundary conditions are used to derive the shielding effectiveness (SE) equations.

An experiment is carried out to verify the validity of the theory developed for magnetic fields of transmission lines and the SE provided by the building. An excellent agreement is obtained for experimental and theoretical results.

1. Introduction

For the last two decades, research has increased and it also focuses on the effects of ELF electric and magnetic fields. The epidemiological studies have found associations between increased cancer risk and power lines configurations, which are thought to be surrogates for magnetic fields.

When transmission lines carrying very high voltages are constructed, the minimum vertical and horizontal distances from the ground must be specified and humans must not be allowed to enter the right-of-way(ROW) region.

The problem of SE computation of conducting shields on incoming radiation has recently been raised to a position of practical importance after the adoption of plastics with conductive coatings for electronic equipment housings.

The SE is defined as the ratio of field strength at a particular point with and without an enclosure. The exact evaluation of electric and magnetic field at any arbitrary point within a cavity involves the study of a three region model: the outside region, the inside region, and the region occupied by the shielding material.[1-4]

The problem of calculating SE is yet unsatisfactory, because the common methods are limited to ideal shapes, such as a circular cylindrical shell or a sphere.

The ideal shapes possess a homogeneous internal magnetic field amounting a locally independent SE. However, the field inside real enclosures is inhomogeneous, and consequently the SE depends on the location considered. Analytical solutions for those shapes do not exist. The SE for complex geometrical shapes must be derived by means of permissible simplifications.

2. The EM Fields due to Currents in High Voltage Transmission Lines

Measuring the magnetic fields around transmission lines and living close to them is extremely hazardous. Thus, a theoretical study that explains the variation in the EM fields at a specified distance from the cables will be presented in this section. We will assume the cables are equally spaced and carrying balanced three-phase currents given as follows:

$I_R = I_m\cos(\omega t)$
$I_S = I_m\cos(\omega t-120)$
$I_T = I_m\cos(\omega t+120)$

where I_m is the instantaneous peak current.

The following figure, fig.1, illustrates the general layout:

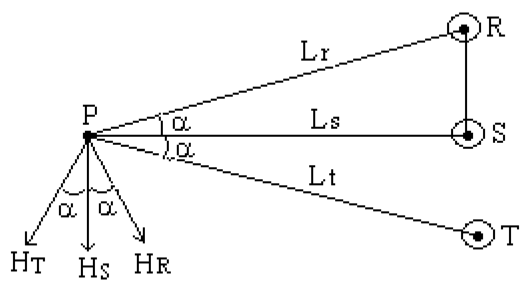

Fig.1 Magnetic field at vertical point P

The magnetic field generated at each conductor current at point P will be:

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle Theoretical and Experimental Study of EM Fields and Shielding Effectiveness Due to High Voltage Transmission Lines	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Department of Electrical-Electronics Engg 80815 Bebek, Y stanbul, Turkey	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom., The original document contains color images.	
Abstract	
Subject Terms	
Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU
Number of Pages 4	

$$H = \frac{I}{2\pi x}$$

where I is the line current and x is the distance between the conductor and P. Thus,

$H_R = I_R/2\pi L_r$; $H_S = I_S/2\pi L_s$; $H_T = I_T/2\pi L_t$

The resulting magnetic field at P will have a component, H_p parallel to the plane of the three cables given by:

$$H_P = H_S + H_R\cos(\alpha) + H_T\cos(\alpha) \quad (1)$$

where $\alpha = \tan^{-1}(h/L_s)$.

Similarly, the magnetic field at P vertical to the plane of the three cables will be H_V

$$H_V = H_R\sin(\alpha) - H_T\sin(\alpha) \quad (2)$$

Fig.2 illustrates the dependence of the compound transmission lines magnetic field intensity of the 380kV, which is the highest voltage in Turkey.

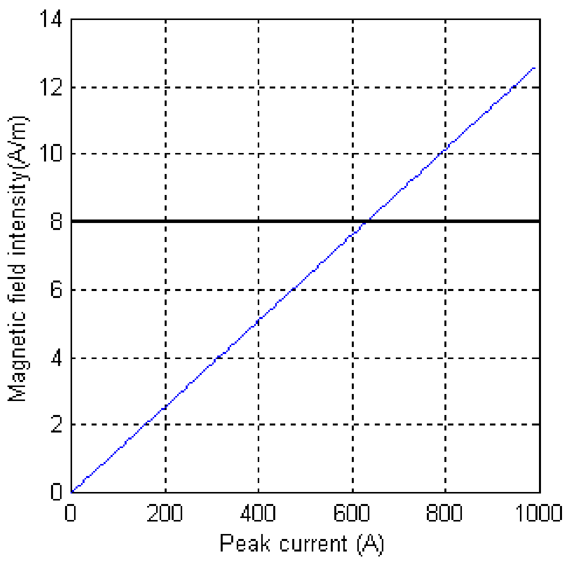

Fig.2 The total magnetic field intensity vs peak current(Im) for transmission lines

Assuming the lines are 16 meters above the ground, the magnetic flux intensity curve is drawn 1 meters above the ground and the lines are separated by 1.5 meters. According to International Commission on Non-Ionizing Radiation Protection(ICNIRP), the public exposure limit of magnetic flux density for people is 100μT = 1G. Using the relation $B = \mu_0 H$ [5] leads to the magnetic field intensity to be 80A/m. However, this magnetic field intensity value is in fact very high and when transmission systems are design one tenth of 80A/m, or 8 A/m is considered to be the limit. As fig.2 illustrates this limit is exceeded if the current of the transmission lines is greater than 630A.

Fig.3 illustrates the dependence of the compound magnetic flux density on the distance from the 3 phase transmission lines. Assuming the lines are separated by 1.5m, the continuous curve is drawn when the line current is 800A(which is the maximum peak current of the lines), and the dashed one is when the line current is 80A(which is the minimum peak current of the lines). Therefore, for 800A case, getting close to the lines more than 18 meters is dangerous for human health.

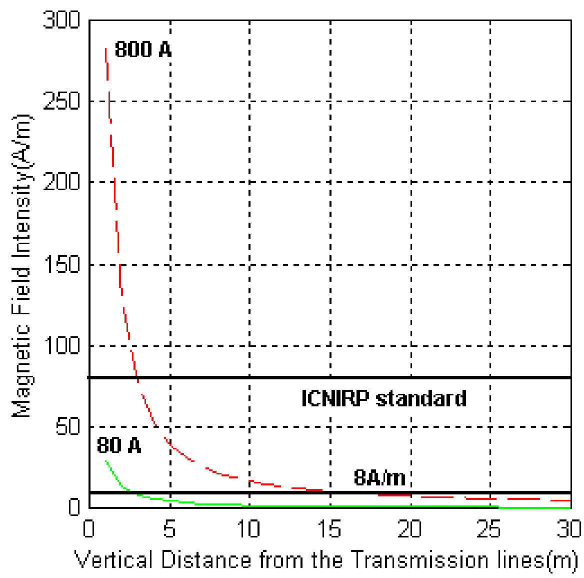

Fig.3 The total magnetic field intensity vs vertical distance for transmission lines

The following figure 4 shows the configuration of the horizontal distance from the transmission lines:

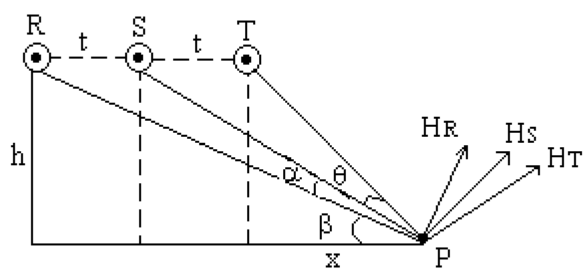

Fig.4 Magnetic field vs horizontal distance

In this case,

$$H_p = H_R\sin(\beta) + H_S\sin(\alpha+\beta) + H_T\sin(\alpha+\beta+\theta)$$

and

$$H_v = H_R\cos(\beta) + H_S\cos(\alpha+\beta) + H_T\cos(\alpha+\beta+\theta)$$

Fig.5 illustrates how the total magnetic field intensity varies with respect to horizontal distance from the 3 phase transmission lines. The continuous curve is drawn for the current 800A, and the dashed one is for 80A. The 8 A/m limits are exceeded when the horizontal distance is 1m for 800A and never for 80A. The lines are assumed to be 21m above the ground and the vertical distance from the ground is assumed to be 1m and the transmission lines are separated by 1.5m.

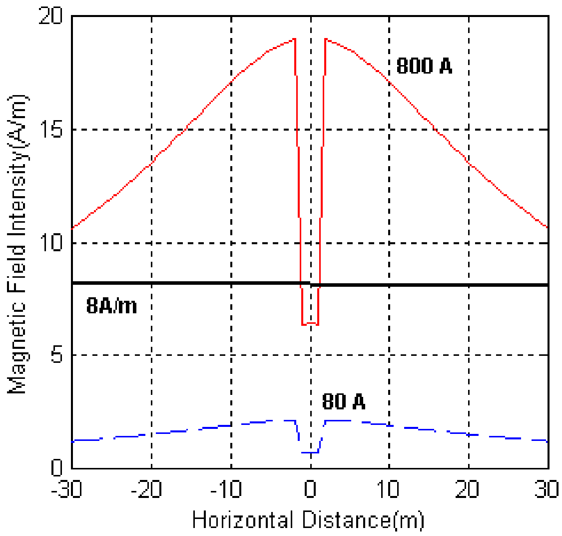

Fig.5 The total magnetic field vs horizontal distance

3. The Calculation of SE

Presently, there are several methods of analysis of shielding effects each involving various degrees of approximation. The method we used is the classical boundary value method, which has been applied to uniform plates, cylinders, and spheres. An exact treatment of non-uniform shields is presently not available even for these idealized spheres[2]

A magnetic shield works by both absorbing and redirecting magnetic lines of flux. The complex SE is defined as H_o/H_i, where H_o and H_i are the outer and inner magnetic fields, respectively.[1]

3.1 Cylindrical Enclosure

For a hollow shielding cylinder of infinite length, inner radius of a, outer radius of b, relative permeability of μ_r, conductivity of σ and thickness t, the ratio H_o/H_i is considered as a measure of shielding effectiveness,[1]

$$\frac{H_0}{H_i} = \frac{2\mu_r}{2\mu_r \cosh(\gamma t) + \gamma a \sinh(\gamma t)} \tag{3}$$

where $\gamma = (1+j)/\delta$ is the propagation constant in the metal, and the skin depth is $\delta = 1/\sqrt{\pi f \mu \sigma}$.

When Bode plots of SE with respect to its parameters are plotted, it is observed that as μ_r, σ, and thickness(t) of the material are increased. Increase in SE means that the H_o/H_i ratio increases. Since the magnetic field produced by the current is H_o and the shielded one is H_i, H_i must decrease because H_o remains constant.

3.2 Rectangular Enclosure

For the rectangular enclosure, assume the inner horizontal and vertical distances a and b, respectively; then the shielding effectiveness of a rectangular enclosure is approximately[2]

$$\frac{Ho}{Hi} = \frac{2(a+b)\mu_r}{2(a+b)\mu_r \cosh(\gamma t) + \gamma ab \sinh(\gamma t)} \tag{4}$$

where γ is as before.

4. Experimental Results

An experiment is carried out to check the validity of the theory. The transmission lines has the peak current of 90A and 380kV when the experiment was performed. The transmission lines are 29m above the ground and the measurement is carried out 1.5m above the ground. The experimental configuration was as shown in figure 6:

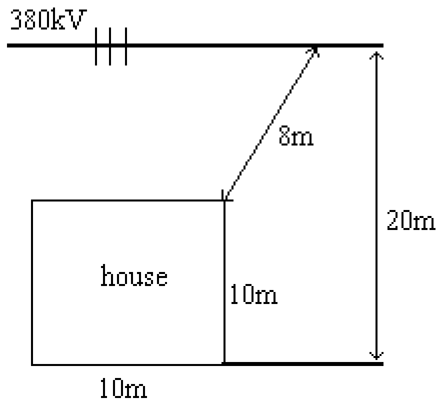

Fig.6 The experimental set up

The following table illustrates the measured and calculated values of magnetic flux density at various horizontal distances from the house to the transmission lines:

Horizontal distance(m)	Hmeasured	Hcalculated
0	1.99	1.90
1	2.02	1.92
2	2.06	1.93
3	2.08	1.96
4	2.11	1.98
5	2.12	2.0
6	2.13	2.02
7	0.72	0.63
8	0.72	0.65

The following figure, fig.7, shows the measured values of magnetic flux density at various horizontal distances from the house to the transmission lines:

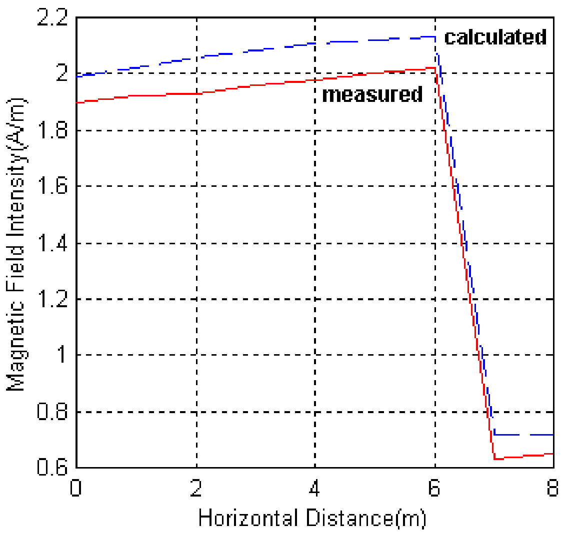

Fig.7 Measured and calculated magnetic flux density values at various horizontal distances

The magnetic field intensity just inside the building at is measured to be 0.99 A/m. In this case, the experimental SE is 20log(1.9/0.99) = 5.66dB. If we use (4) with the parameter values a = b= 10m, t =0.25m, μ_r = 5, and σ = 100, then the SE is calculated to be 5.84dB.

5. Discussion and Conclusion

Electric fields from power lines are relatively stable because line voltage doesn't change very much. Magnetic fields change greatly as current changes due to changing loads as seen in the previous figures.

The strength of the EM fields from high voltage transmission lines decreases rapidly with increasing distance as seen from the figures.

The SE relations for cylindrical, rectangular and arbitrary cross section enclosures are valid for alternating currents having maximum 10kHz frequency. At 50 Hz we found out that SE is not depend on cross section of the enclosure. As the frequency of the source is increased, the relative permeability of the material providing the SE increases. Therefore, it should be expected to have more shielding at 10kHz than at 50Hz.

When the relative permeability and conductivity of materials are examined it is noted that there is generally an inverse relationship between the relative permeability and conductivity of the materials. Therefore, as always we have a trade off when deciding to chose the shielding material. To overcome this limitation high permeability materials of alloys are used.[6]

5. References

1. A. Aiello, M.Righetti, G.Tribellini "A Theoretical Model for Thin Shield Effectiveness of Rectangular Cases" EMC96 Trans. *Electromagnetic Compatibility* pp: 540-544, 1996
2. W.W. Cooley "Low-Frequency Shielding Effectiveness of Non-uniform Enclosures", IEEE Trans. Electromagnetic Compatibility, pp:34-43, 1968
3. P. Kistenmacher, A.Schwab "Low-Frequency Effectiveness of Inhomogeneous Enclosures" Proc. IEEE Electromagnetic Compatibility Symposium Santa Clara, CA, pp: 347-352, 1996
4. T. M. Lee, L. J. Cao "EMI on Computers Caused by Riser Cables " Proc. International Conference on Advances in Power Systems, Control, Operation and Management, APSCOM-95, pp: 67-70, 1995
5. ICNIRP Guidelines "Guidelines for Limiting Exposure to Time-varying Electric, Magnetic, and Electromagnetic Fields" Health Physics pp:494-522, 1998
6. D.Grilli, J.R. Lucker, www.rbITEM.com, pp:178-180, ITEM 2000

Acknowledgement: This work was supported by B.U. Research Foundation Project No: 00A201.